Chapter 13 Temperature and Kinetic Theory

[A] Thermal Expansion

To date:

Mechanical:
- Kinematics: $x = x_0 + v_0 t + \frac{1}{2}at^2, \ldots$
- Newton's Laws: $\sum \vec{F} = m\vec{a}$
- Energy: $E_{TOT} = \frac{1}{2}mv^2 + mgh + \frac{1}{2}kx^2$
- Momentum: $p = mv$ (linear) $F \cdot \Delta t = p$ (impulse)
- Rotation: $\omega = \frac{\Delta\theta}{\Delta t}$, $\omega_f^2 = \omega_0^2 + 2\alpha\theta, \ldots$
- Ang. Mom: $\tau = \frac{L}{t}$
- Statics: $\sum F = 0$, $\sum \tau = 0$, E, B
- Fluids: $P = \rho g h$, $\rho A V = \text{const}$. Bernoullis
- Oscillations: $\omega = \sqrt{\frac{k}{m}}, \ldots f = \frac{1}{T}$
- Sound: , $\lambda_n = 4l/n$, $n = \text{odd} \ldots$

Thermo mechanical:
- Temperature (Kinetic Thy):
- Heat:
- 1st Law of Thermo: Refrigerators, Carnot

* <u>Atomic Motion</u> 1827: Dr. Brown noticed that even in still quiet air there was motion on the microsopic scale. "Brownian Motion" This helped to formulate the <u>atom</u> as the smallest element of matter.

* The Atom:

atomic mass (molecular mass, atomic weights)

atomic unit $1u = \frac{1}{12}$ the atomic weight of the Nitrogen (N) atom.

$$1u = 1.6605 \times 10^{-27}\ kg$$

[EX] Hydrogen = 1.0079 u

* elements are these atoms in the periodic table of the elements: H, He, B, Ca, etc. Au

* elements bond together into <u>molecules</u> H_2O
* different molecules form Chemical compounds

* Distance between atoms (ex: copper Cu)

Cu has a density of $\rho = 8.9 \times 10^{3} \frac{kg}{m^3}$ and each Cu atom is 63u

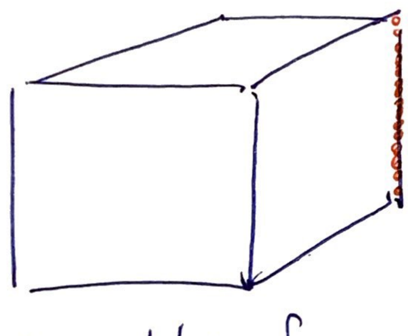
- $63u = 63u \cdot \left(1.66 \times 10^{-27} \frac{kg}{u}\right) = 1.05 \times 10^{-25}$ kg/atom (Cu)

- The number of atoms then in one kg

$$\left(\frac{1 \text{ atom}}{kg} = \frac{1}{1.05 \times 10^{-23} \, kg}\right) * 8.9 \times 10^{3} \frac{kg}{m^3}$$

$$= \boxed{8.5 \times 10^{28} \text{ atoms}/m^3 \text{ for copper}}$$

- $\sqrt[3]{8.5 \times 10^{28} \text{ atoms}/m^3} = 4.4 \times 10^{9}$ atoms/m along an edge of the 1m × 1m × 1m box.



- The size then of one atom:

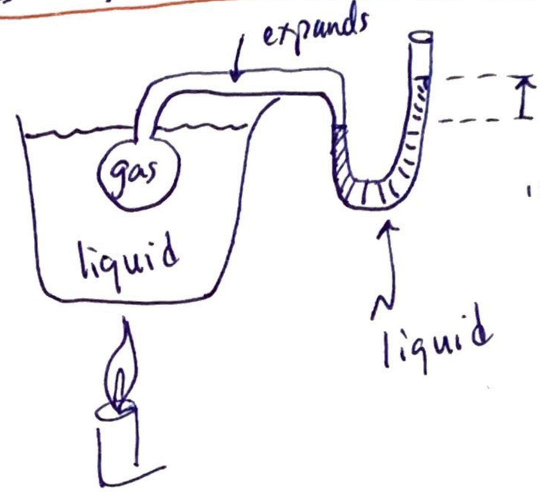
$$1m / 4.4 \times 10^{9} \text{ atoms} = \boxed{2.3 \times 10^{-10} \text{ m/atom}}$$

size of a copper atom

* **Temperature** is proportional to the speed of the atoms in matter. (Gas)

Compress a gas (then the walls move inward).

* Galileo was the 1st to use the expansion of gas to measure temperature:



column expands.

"constant-volume gas thermometer"

* **Thermal Equilibrium**

0th - Law of Thermodynamics basically applies the Law of Transitivity seen in math & logic

if A = B
& B = C
then A = C

" If two systems are in thermal equilibrium with a third system, then the two systems is in equlibrium with themselves "

[A|B] [B|C] then [A|C]

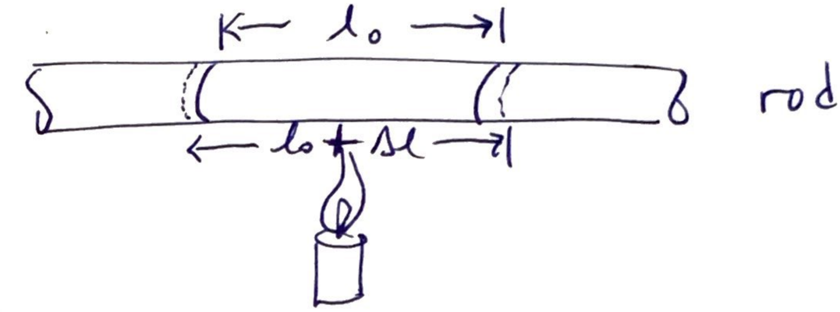
B can play the role of a thermometer.

* thermal expansion

materials change their lengths when they change temperature.

Most of the time when you cool an object it shrinks. (exception ice/water)

- 1-Dim:



we find that

$\Delta l \propto l_0$, and $\Delta l \propto \Delta T$

Together $\boxed{\Delta l = \alpha l_0 \Delta T}$

↖ constant of proportionality

Called the...

α = Coefficient of Linear expansion

Exaples: Al $\alpha = 25 \times 10^{-6} / C^\circ$ steel $\alpha = 12 \times 10^{-6} / C^\circ$

Pyrex $\alpha = 3 \times 10^{-6} / C^\circ$

Glass $\alpha = 9 \times 10^{-6} / C^\circ$

liquids have no "Linear expansion"

EX Golden Gate Bridge is made of steel.

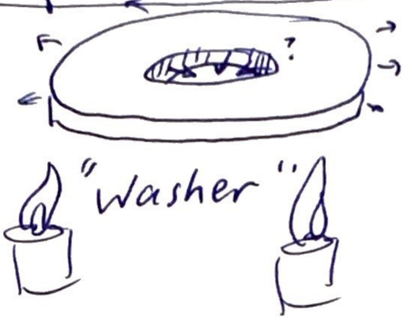
$l_0 = 2000\,m$ @ $T = 20^\circ C$

Shrink

@ $-30^\circ C$: $\Delta l = \alpha l_0 \Delta T = (12 \times 10^{-6} / C^\circ)(2000\,m)(50^\circ C) = 1.2\,m$

@ $40^\circ C$: $\Delta l = \alpha l_0 \Delta t = (12 \times 10^{-6} / C^\circ)(2000\,m)(40-20) = 48\,cm$

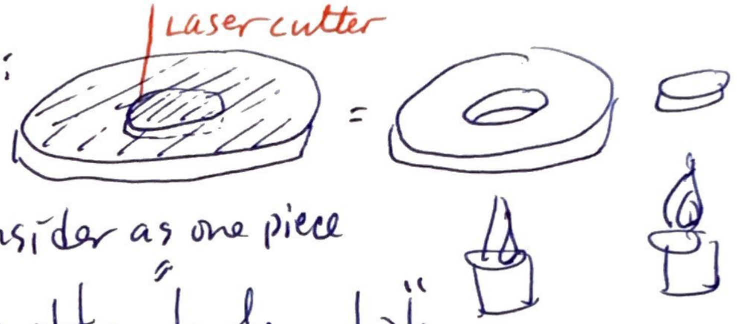
• Conceptual Idea



Consider a washer...

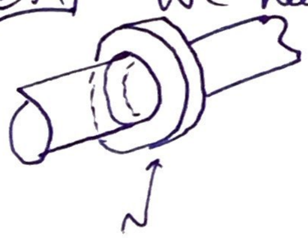
Q: As we heat this up does the hole get larger or smaller?

A:



If we heat both up the "hole-disk" will expand and must still fit inside the washer. But the "hole-disk" expanding means the hole in the washer must expand also.

EX We need to fit a metal ring onto a metal rod.



@ 20°C • the diameter of the rod is 6.445 cm
• The inside diameter of the washer is 6.420 cm

If we need 0.008 cm clearance to slid the ring on, How hot do we need to heat the ring up.

$$\Delta T_{ring} = \frac{\Delta \text{diameter}}{\alpha_{iron} D_0} = \frac{[6.445\text{ cm} + 0.008\text{ cm}] - 6.420\text{ cm}}{(12 \times 10^{-6}/C^\circ)(6.420\text{ cm})}$$

or $\Delta T = 430°C$ needed to expand the ring & its hole

• So starting @ room temperature of 20° we need to heat the ring to 450°C

*Volume Expansion

$T_{final} - T_{initial}$

$$\Delta V = \beta V_0 \Delta T$$

β = coefficent of volume expansion

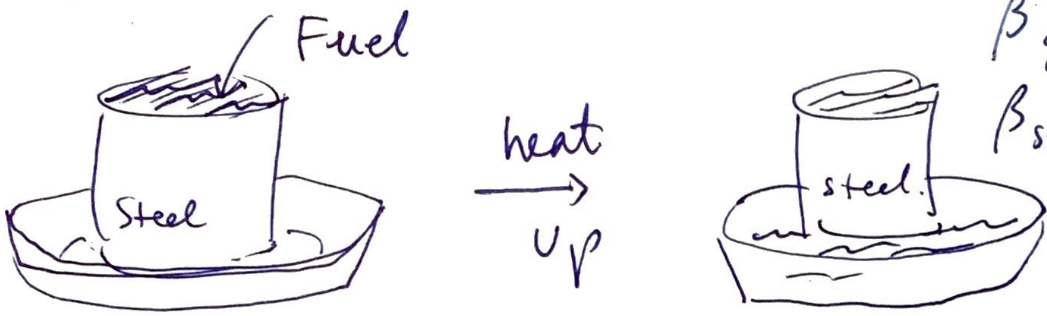
This applies to liquids and solids.

EX A 70 L steel fuel tank is topped off @ 20°C but then the sun rises and the Temp goes up to 40°C

a. How much fuel spills out?

$\beta_{gas} = 950 \times 10^{-6} /°C$

$\beta_{steel} = 35 \times 10^{-6} /°C$



20°C 40°C

$$\Delta V_{fuel} = (950 \times 10^{-6} /°C)(70\,l)(40°C - 20°C)$$
$$= \underline{1.3\,l \text{ expansion}}$$

Q: So does this mean 1.3 l spill over board?

A: No, the steel container itself expands.

$\Delta V_{tank} = \Delta V_{solid\ tank}$

$$= (35 \times 10^{-6} /°C)(70\,l)(40°C - 20°C)$$
$$= \underline{0.049}\,l \text{ expansion}$$

So only 1.3 l − 0.049 l spills out = $\underline{1.2951\,l}$

* We can discuss <u>thermal stresses</u> now.

Before in ch 9: $E = \frac{\text{stress}}{\text{strain}} = \frac{F/A}{\Delta l / l_0}$

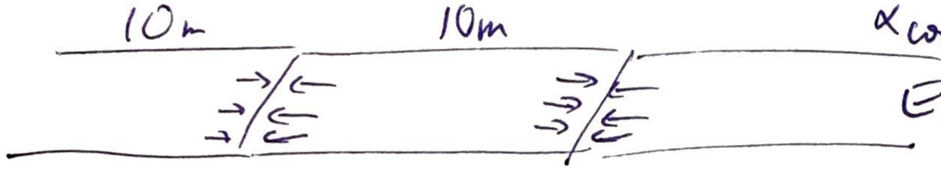
Now $\Delta l = \alpha\, l_0\, \Delta T$

$$\frac{F}{A} = \alpha E \Delta T$$

↑ change in pressure as there is a temp. change.

EX Consider a 10m long concrete slab on the freeway that undergoes a $\Delta T = 30^\circ C$ temp swing from morning to afternoon.

What pressure does it exert on the neighboring slabs?



$\alpha_{concrete} = 12 \times 10^{-6} /{}^\circ C$

$E_{concrete} = 20 \times 10^{9}\ N/m^2$

pressure: $\frac{F}{A} = \alpha E \Delta t$

$= (12 \times 10^{-6} /{}^\circ C)(20 \times 10^{9} \frac{N}{m^2})(30^\circ C)$

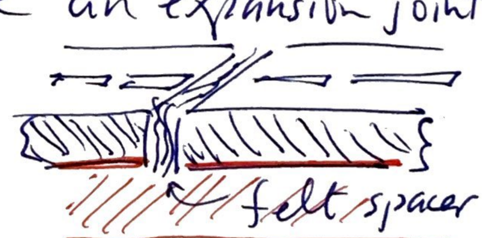
$= 7.2 \times 10^{6} \frac{N}{m^2}$

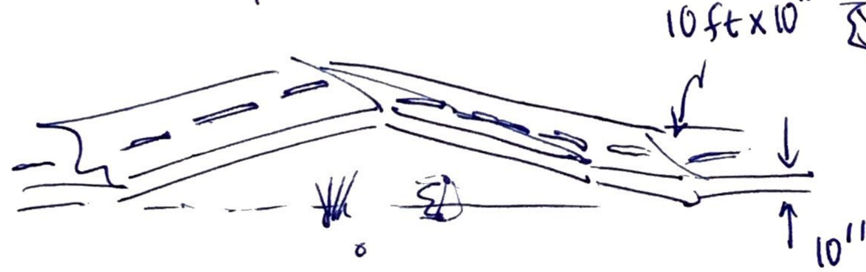
7 million Pascals

(1000 lbs/in²)

neighbors also produce 7 million Pas. (7+7=14)

this is why the slabs have an expansion joint so they don't touch.





$120 \times 10 = 1200\ in^2$

$\times 1000\ lb/in^2 = 1{,}200{,}000$